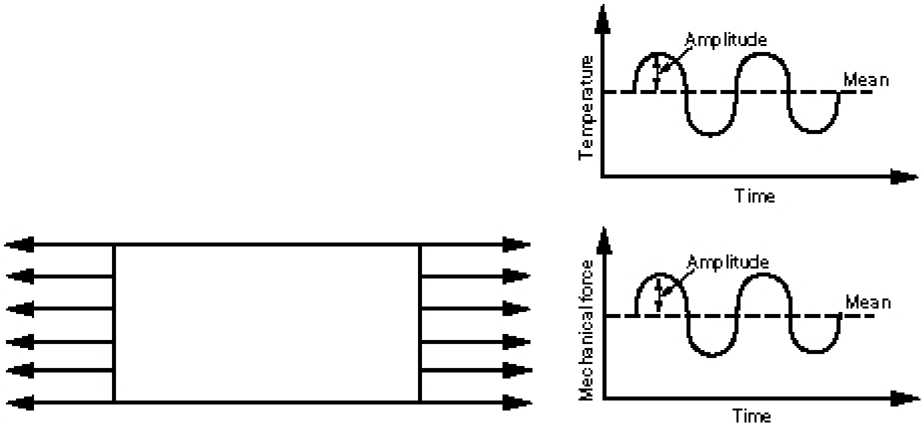
Effect of Cyclic Thermal Loads on Fatigue Reliability in Polymer Matrix Composites

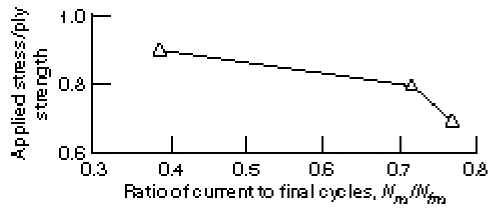
Technological solutions that will ensure the economic viability and environmental compatibility of a future High Speed Civil Transport plane are currently being sought. Lighter structural materials for both airframe primary structures and engine structure components are being investigated. We believe that such objectives can be achieved through the use of high-temperature composites as well as other conventional, lighter weight alloys. One of the prime issues for these structural components is assured long-term behavior with a specified reliability.



Thermomechanical cyclic load.

An investigation was conducted to describe a computational simulation methodology for predicting fatigue life (see the figure above), reliability, and probabilistic long-term behavior of polymer matrix composites. A unified time-, stress-, and load-dependent Multi-Factor Interaction Equation (MFIE) model developed at the NASA Lewis Research Center was used to simulate the long-term behavior of polymer matrix composites.

To illustrate the application of the methodology, we chose a typical composite system consisting of graphite fibers in an epoxy matrix with a layup of $(0°/\pm45°/90°)_s$. This methodology can be applied to other types of polymer matrix composites as well. The cumulative probability distribution functions for the fatigue life cycles were computed for different thermal cycle rates and constant applied stress. The laminate strength was evaluated on the basis of first-ply failure criteria (hereinafter referred to as laminate strength). First-ply failure criteria assumes that a laminate has failed when any stress component in a ply exceeds its respective allowable. Using these cumulative probability distribution functions, one obtains a fatigue life cycle curve for a reliability of 0.999 (as in the following figure). The results show that, at low mechanical cyclic loads and low thermal cyclic amplitudes, fatigue life for 0.999 reliability is most sensitive to the matrix compressive strength, matrix modulus, thermal expansion coefficient, and ply thickness. In contrast, at high mechanical cyclic loads and high thermal cyclic amplitudes, fatigue life at 0.999 reliability is more sensitive to the shear strength of the matrix, longitudinal fiber modulus, matrix modulus, and ply thickness.



Fatigue life variation resulting from the thermomechanical cyclic load on 0.127-mm plies of graphite/epoxy in a (0°/45°/90°)$_s$ laminate configuration. Mean applied load, 50 percent of ply strength; mean temperature, 65.5 °C; and cyclic temperature, 51.7 °C.

Lewis contact: Dr. Christos C. Chamis, (216) 433-3252, smccc@popserve.grc.nasa.gov
Author: Dr. Christos C. Chamis
Headquarters program office: OA